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Editor
BENEDICT F. MASSELL, M.D., Boston

Associate Editor
GORDON S. MYERS, M.D., Boston

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THE PRACTICAL VALUE OF PHONOCARDIOGRAPHY

The role and clinical applications of phonocardiography are still somewhat controversial. Therefore, it will be useful to re-examine them in the light of recent contributions and of the experience gained by the author through routine clinical application of this method for over ten years.

It is not unusual that a phonocardiogram is requested in order to settle heated discussions between experienced physicians. This proves how subjective auscultation is and indicates that phonocardiography cannot be considered without reference to the laws and limitations of clinical auscultation.

THE LAWS OF AUSCULTATION AND THE PHONOCARDIOGRAPHS

The Ear. It is well known that the human ear is an imperfect instrument.[1] Knowledge of its limitations may explain some of the pitfalls of auscultation and certain unavoidable discrepancies between clinical impression and objective graphic data. These limitations may be summarized as follows:

(a) Pure tones of different pitch and the same intensity are heard like tones of different intensity.

(b) The ear detects more easily changes of pitch than changes of intensity (except in the lower frequency range where changes of pitch may not be detected). As a result, a higher pitched tone may be heard as a louder tone.

(c) The ear is sensitive to vibrations between 20 and 20,000 cycles per second; however, sensitivity is poor for the lower pitched vibrations and becomes gradually better for the higher pitched. The heart is the source of vibrations between 5 and 800 per second (soft murmurs exceptionally reach 1000). Therefore, many cardiac vibrations are in the range of infra-sounds (non-audible sounds) while others are heard only if very loud or by particularly sensitive and trained observers.

(d) The scale of sensitivity of the ear with regard to frequency increases very rapidly, on a logarithmic ratio. In the frequency band of 1,000 cycles, a given increase of intensity results in the same increase in loudness; while in higher frequency bands, lesser increases of intensity cause the same result.

(e) In the presence of certain loud or high-pitched sounds, the ear may be unable to detect weaker or lower-pitched sounds which follow immediately. This phenomenon is called "masking."

The Apparatus. Modern registration is based on the use of three crystal microphones:[2]

(a) The linear microphone, which gives a correct and uniform response to all mechanical vibrations set up by the heart, is used mainly for the study of low-frequency vibrations, like those representing the thrust of the apex or the pulsations of various areas of the chest (regional cardiograms).[3] The phases of the valvular events, as well as those of systolic emptying and diastolic filling of the ventricles, are well recognized in these tracings. This microphone is also used for sphygmography.

(b) The stethoscopic microphone eliminates only those low-frequency vibrations which have no acoustic value. It records all the others with a rising type of amplification so that the resulting picture corresponds to that presented to the ear by a stethoscope. This microphone is not hampered by the failures of the human ear and has a greater range than the latter because it records also vibrations which are poorly heard or are inaudible (infra-sounds). This microphone is used for a basic study of the patients.

(c) The logarithmic microphone attenuates all low-frequency vibrations including those which are in the low range of audibility. Recording is obtained by increasing on a logarithmic scale the amplification. This magnifies tremendously the high-pitched vibrations. The tracing may be compared to a picture of the sounds heard by an observer because it excludes the poorly audible sounds and brings out with clarity the rapid vibrations of the soft, high-pitched murmurs. This microphone is used for checking clinical impressions and for the best recording of soft murmurs.

The sound tracings should be checked against other records, like the electrocardiogram, the phlebogram, and the apex cardiogram (linear microphone). Thus, the exact beginning and the end of systole and the different phases of diastole can be accurately recognized. It is not unusual for sounds or murmurs to be considered clinically in one phase of the cardiac cycle while phonocardiography proves them to be in another. This discrepancy is partly due to the fact that

auscultation lacks an exact and absolute timer of sounds.

Calibration. The problem of calibration of the intensity of sounds and murmurs has been a stumbling block for several decades. An electric device has been introduced in the new Sanborn twin-beam apparatus.[24] An acoustic calibrator is now being studied by the author. Both should be used in the future, each complementing the other.

THE NORMAL HEART SOUNDS

The phonocardiogram of a normal subject may record up to four main heart sounds. The two louder sounds are called the 1st and 2nd sound; the others, the 3rd and 4th sound. The 3rd and 4th sound take place during diastole and are connected with the phases of ventricular filling (rapid passive filling = 3rd sound; rapid active filling caused by atrial contraction = 4th sound), therefore, they may be called *diastolic sounds.*[6, 7] The more commonly heard and louder 1st and 2nd sounds are strictly connected with ventricular systole (beginning of systole = 1st sound; end of systole = 2nd sound). It has been suggested[6,7] that they be called *systolic sounds* (fig. 1).

The *first sound* is caused by so complex a musculo-valvular mechanism that it is impossible to attribute special vibrations to any separate factor.[8] On the other hand, two groups of higher vibrations within this sound-complex coincide in time with the closing of the a-v valves and the subsequent opening of the semilunar valves.[8, 9] Thus, information can be obtained about these valvular events. Occasional audible splitting of the first sound may be caused by incomplete fusion of these two groups of vibrations.

The *second sound* is usually simpler and shorter. Its main group of vibrations is due to closing of the semilunar valves, and a study of these vibrations can give information about the function of the aortic and pulmonic valves. A small vibration frequently visible at the end of this sound-complex is caused by the subsequent opening of the mitral valve. This vibration is occasionally higher and may become audible in normal subjects[2, 3, 10] (opening sound of the mitral valve); it is frequently loud, snapping, and delayed in mitral stenosis (opening snap of the mitral valve) giving the auditory impression of a reduplicated 2nd sound. The diagnostic importance of this "snap" has been repeatedly emphasized since Potain.

The *third sound* and *fourth sound* consist usually of one or two small, low-pitched vibrations; they are audible in children, young adults, or persons with a thin, flat chest. Their increased loudness is the most common cause of the "triple rhythms" (so-called gallop rhythms) described below.

The duration of the first and second sound, as well as of their phases, and the intervals separating these sounds from each other have been repeatedly investigated,[2, 9, 10, 12] so that tracings of cases under observation can be evaluated with the help of average and extreme figures.

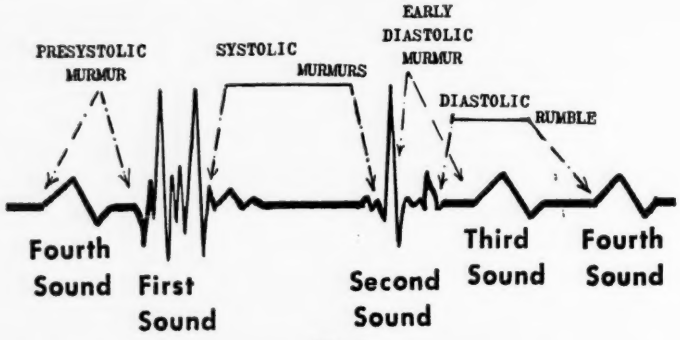

Fig. 1

Sketch of a phonocardiogram recorded with the stethoscopic microphone. Location of most common murmurs.

GENERAL APPLICATIONS

Phonocardiography can be used: (a) For the study of patients with unusual heart sounds, abnormal auscultation rhythms, or murmurs. Thus, it should be part of the routine clinical study as a complement and refinement of the common stethoscope. (b) For the study of fetal heart sounds and murmurs, permitting a more thorough study of the fetal heart and prenatal diagnosis of congenital defects. (c) As the most accurate timing method to be recorded together with other graphic, clinical, or experimental tracings, like the electrokymogram, esophagocardiogram, pneumocardiogram, or ballistocardiogram.

MURMURS

Cardiac murmurs are transcribed as complex groups of vibrations. It is easy to decide whether these vibrations are low-pitched (more separated) or high-pitched (near and packed together); whether they correspond to a rumble (sparse and irregular vibrations), or whether the murmur is musical (regular vibrations).

The relationship of these vibrations to the heart sounds indicates whether the murmur is systolic, early-diastolic, or presystolic* (fig. 1).

*The clinical term of "mid-diastolic murmur" is frequently inaccurate. A murmur is a prolonged series of vibrations. Only in rare cases is diastole so long and is the murmur so placed that such a term is justified.

The graphic disposition of the vibrations has led to recognition of several types of murmurs. The most important are: (a) A murmur in decrescendo (typical of mitral or aortic insufficiency). (b) A diamond-shaped murmur (typical of aortic or pulmonic stenosis). However, other types of murmurs can be observed in aortic and mitral insufficiency and in aortic stenosis. (c) A crescendo-type of presystolic murmur (typical of mitral stenosis with sinus rhythm). The murmur of mitral stenosis actually may not be in crescendo, if observed on tracings. On the other hand, if the first sound is in crescendo, the observer erroneously recognizes a presystolic murmur, a pitfall which cannot be avoided by auscultation alone. (d) Either a continuous murmur, or a murmur which rides over the second sound being late-systolic and early-diastolic (typical of patent ductus arteriosus and a-v fistula).

Functional systolic murmurs have long been recognized; whereas *functional diastolic murmurs* have been demonstrated only recently. Frequently phonocardiography permits diagnosis of a functional murmur when the vibrations are few, are too small, are located in a different phase from that admitted through auscultation, or represent sounds not murmurs. However, there are cases where graphically recorded functional murmurs simulate murmurs caused by organic lesions, not only during systole but also in diastole.[13,14] It was proven recently that quite often an apical diastolic murmur not caused by organic lesions is louder and is recorded over a wider area of the precordium than that of mitral stenosis.[25]

TRIPLE RHYTHMS

This name has been suggested[15] to indicate the presence of a cadence of the heart sounds which is caused by the addition of one extra-sound to the two more commonly heard. An older and better known term was gallop rhythm. However, the new definition is more comprehensive (fig. 2).

Until recently, a gallop was considered as a purely clinical and auscultatory phenomenon. Phonocardiography revealed the frequent occurrence of diastolic sounds in tracings of normal subjects in whom auscultation revealed only a two sound rhythm. Therefore, the problem of whether a triple rhythm was physiological or pathological was revised on the basis of graphic data.[16] A diastolic sound may not be audible because it is low-pitched, weak, or too near the first sound. Therefore, it was suggested[16] to consider pathological any diastolic sound which had a frequency of vibration of 30 or more per second, or an amplitude greater than ⅔ of the first sound at the apex, or both.

Addition of a Diastolic Sound (Diastolic Gallops). Three types have been recognized:[17,18,19]

(a) *Ventricular type.* It is caused by increased loudness or high pitch of the third sound and takes place in early diastole at the time of rapid ventricular filling. It is not unusual in normal subjects under the age of 40, but it is more common in individuals with rheumatic or congenital heart disease. It is more readily produced in the presence of tachycardia. Whenever it is found in subjects over 40, it represents evidence of severe ventricular strain and indicates a less favorable prognosis.

(b) *Atrial type.* It is caused by increased loudness or high pitch of the fourth sound and takes place in presystole at the time of the atrial contraction. It is not uncommon even in normal subjects over the age of 40. It is favored by prolongation of the a-v conduction and is more common in coronary or hypertensive heart disease. Whenever it is found in younger subjects, it represents the result of atrial engorgement and indicates a less favorable prognosis.

(c) *Summation type.* It is caused by the summation of the third and fourth sound in

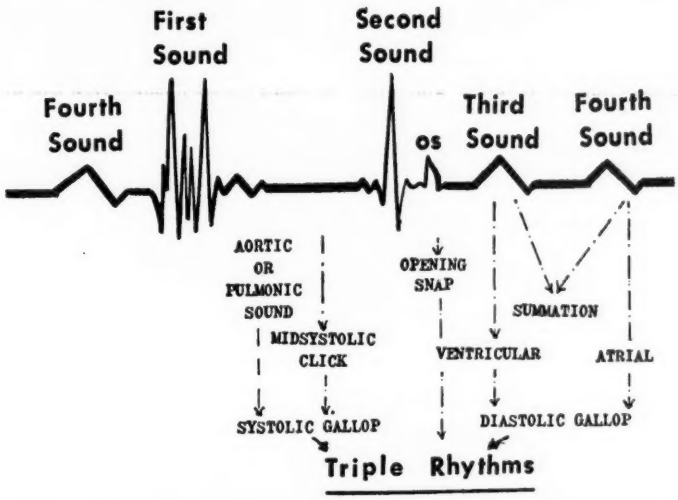

Fig. 2

Sketch of a phonocardiogram as in Fig. 1. Location of the most common extra sounds which cause triple rhythms.

mid-diastole, and the resulting sound may be complex and prolonged.

Addition of a Sound in Systole (Systolic Clicks or Snaps). Several types have been described:

(a) There may be addition of a low-pitched sound in early-systole, over either the aortic or the pulmonic areas.[20] It is due to sound vibrations arising in the vascular walls because of increased pressure in, or pathology of, one of the larger arteries.

(b) There may be a loud and rapid vibration near mid-systole, usually heard and recorded best at the apex. It has been attributed to traction of pleuro-pericardial or diaphragmo-pericardial adhesions.[20]

(c) A third type is encountered in cases of congenital heart disease with an overriding aorta, especially in the syndrome of Fallot. It is recorded best over the mid-precordium.[23, 3]

Increased Loudness of the Opening Sound of the Mitral Valve. Though rare, an audible opening sound of the mitral valve may be found in normal subjects.[8, 10] Patients with mitral stenosis, however, frequently present a loud snap, coinciding with and caused by the opening of this valve. The sound is high-pitched and may be heard over the entire precordium. It is recorded best over the 3rd and 4th left interspaces.

Splitting of the Second Sound Due to Asynchronous Closure of the Semilunar Valves. There are two common possibilities:

(a) Early closure of the pulmonic valve may be caused by high pressure in the pulmonary artery. It is frequent in mitral valve lesions and in chronic cor pulmonale.

(b) Non simultaneous closure of the aortic and pulmonic valves may be caused by non simultaneous contraction of the two ventricles (bundle branch block or premature ventricular beats).

It has been stated that bundle branch block causes splitting of both the first and the second sound. Recent studies[21] indicate that splitting of the first sound is very rare and possibly non-existent.

Recognition, differential diagnosis, and meaning of the triple and quadruple rhythms have been already discussed by the author[22] and are omitted here for the sake of brevity.

CONCLUSIONS

Phonocardiography has been developed slowly on account of technical difficulties. Its importance is becoming greater from year to year. One should bear in mind that auscultation and phonocardiography are two inseparable approaches to the study of the same phenomena. Therefore, whenever auscultation is useful, phonocardiography also is of help for diagnosis.

Phonocardiography should not be considered merely as a way to check and confirm auscultatory findings. It is more accurate than auscultation because it is not hampered by various physiological and psychological limitations inherent in auscultation. Having control of subsonic and borderline bands of vibrations, phonocardiography covers a more extensive range.

Differential diagnosis is considerably aided by phonocardiography in patients with the following diseases: Rheumatic heart disease with valvular lesions, luetic heart disease with aortic valve damage or aortitis, calcific aortic stenosis, congenital malformations of the heart and large vessels, bacterial endocarditis, adhesive and constrictive pericarditis, conditions associated with extensive myocardial damage (myocarditis; coronary heart disease; hypertensive heart disease), and disturbances of the heart rate and rhythm.

Aldo A. Luisada
Chicago, Illinois

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